DOCUMENT RESUME

ED 294 718 SE 049 093

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TITLE The Moist Side of Life--Some Classroom Activities in Biological Adaptation.
PUB DATE 88
NOTE 52p.
PUB TYPE Guides - Classroom Use - Guides (For Teachers) (052)

EDRS PRICE MF01/PC03 Plus Postage.
DESCRIPTORS Animal Behavior; *Biological Sciences; Cognitive Development; Cognitive Processes; *Concept Formation; Elementary School Science; Elementary Secondary Education; Epistemology; *Laboratory Animals; *Science Activities; Science Education; *Secondary School Science; Teaching Methods; Zoology
IDENTIFIERS *Crustaceans

ABSTRACT

There is a group of terrestrial crustaceans, the isopods or sowbugs, that spend their lives in the cool, damp and dark microhabitats beneath rocks, decaying logs, and leaf litter. Although these animals are well adapted to exploit these moist niches, they are obligated to live where they do because of their need for moisture and high humidity to prevent dehydration. The activities in this guide are designed to compliment class discussions about how invertebrates and other animals have solved the problem of water and moisture control. This guide includes: (1) a background for teachers; (2) where one can get isopods; (3) the dry and moist side of an isopod's life (an activity); (4) some interesting variations; (5) summary; (6) additional comments and considerations; and (7) a glossary. The activity contains discussions of observations and interpretations of the data collected. The paper concludes with a discussion of the content and process approach to learning and provides a content map and a "V" analysis of the lesson on isopods. (CW)

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THE MOIST SIDE OF LIFE -- SOME CLASSROOM ACTIVITIES IN BIOLOGICAL ADAPTATION

By

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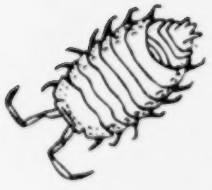

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INTRODUCTION

There is a group of terrestrial crustaceans, the isopods or sowbugs (Figure 1), that spend their lives in the cool, damp and dark microhabitats beneath rocks, decaying logs and leaf litter. And although these animals are well-adapted to exploit these moist "hidden" niches, they are, in fact, obligated to live where they do for one paramount reason -- the need for moisture and high humidity to prevent dehydration (desiccation).

But why is it that isopods are restricted to moist, humid microhabitats, whereas many of their close relatives (the terrestrial insects, for example) can live in, and tolerate, much drier environments? And how do isopods find their way back to moist habitats in the event they either wander too far from their current hiding places, or the rock or log under which they live gets overturned? The activities I will describe in this paper are designed to stimulate class discussions around these questions. I have done these activities with middle and high school students and with preservice elementary and secondary teachers. With some modifications, I believe they can also be used with pupils in the upper elementary grades. They get students to <u>think</u> about the significance of biological adaptations and animal behavior, and they teach important science and mathematics process skills, including: formulation and testing of hypotheses, control of experimental variables, systematic qualitative and quantitative observation, and graphing and interpretation of experimental results.

BACKGROUND FOR TEACHERS

I use the activities to compliment class discussions about how various land animals, particularly invertebrates, have solved several critical and related problems associated with living on land -- how to find water, how to take it in, and how to avoid losing it from the body. I call this the "water-moisture problem" and I explore it with my students within the context of four major conceptual questions, which I will outline and discuss briefly here:

(I) Why do animals need water? --- Water is, of course, essential to life. It is the medium in which all life-sustaining chemical reactions take place, and it transports nutrients and wastes throughout the body. Water is also necessary for breathing. Students usually do not think of this. But no matter what kind of respiratory tract a land animal may have, somewhere along that tract there is a moist membrane that allows oxygen to diffuse into, and carbon dioxide to diffuse out of, the animal. The diffusion of these gases requires moisture, and if the respiratory membranes dry up, the passage of these gases into and out of the bloodstream is no longer possible.

(II) How do animals take in water? --- The obvious answer is -- they drink it. But many land invertebrates, including isopods, can soak up water through their outer body wall, either from moist surfaces with which they are in direct contact, or from

moisture-laden air. Isopods also get much of their water by eating dead plant matter that contains water.

(III) How do animals lose, and avoid losing, water from their bodies? --- This is an important question because it asks students to think about possible adaptations land animals may have developed to prevent them from losing water. Most terrestrial animals lose at least some water directly through their skin. Even humans lose water this way when they perspire. Isopods are notorious for losing water vapor by evaporation through their outer body covering (exoskeleton) when they are exposed to dry conditions. Their exoskeleton is relatively thin, and is highly permeable to water. Insects, on the other hand, have solved this problem by means of a water-impermeable layer of wax that covers the outer surface of their exoskeleton. This is one reason why many insects can tolerate exposure to dry conditions for fairly long periods of time, and why they are able to colonize habitats that are too dry for isopods.

In addition, most animals lose water during the excretion of urine. Once again, the insects (but not the isopods) have tackled this problem, and in a rather unique way. Instead of producing liquid urine, they convert their urine-like waste products into dry, solid crystals (known as "uric acid"), which they excrete -- a superb adapation for conserving body water. Finally, all land animals lose some water from their respiratory membranes, although isopods carry this to the extreme. Since their thin, respiratory membranes are located close to the outer body wall, rather than

being deeply embedded withing the body as in most other land animals (consider the human lung), much water tends to escape across an isopod's respiratory membranes to the outside environment.

Clearly, isopods do not have good adaptations for preventing the loss or evaporation of water from their bodies in dry environments. Consequently, they must "make sure" that they remain in moist, humid places where evaporation is not a serious problem and where plenty of replacement water is available. In short, isopods must rely on specific <u>behaviors</u> that keep them in moist places. This leads to the last major question:

(IV) <u>What types of behaviors might a land invertebrate, such as an isopod, use to find water or moist, humid places?</u> -- Some land invertebrates have moisture/humidity sensing devices or receptors (often located on their antennae) that orient or guide them in a non-random and fairly direct fashion from dry to moist places. As far as we know, isopods do not have such moisture receptors. They depend, instead, on what I refer to as the "risky reflex method" of finding moisture (scientists call it a <u>kinesis</u>). This is how it works: In dry places, isopods begin to lose water vapor through their exoskeleton. This loss of water initiates an <u>automatic</u>, <u>involuntary</u> nervous reflex that causes the animals to become very active and to move about in a <u>random</u> manner. If, as they move, they encounter even drier conditions, they lose even more water and become still more active. But if, <u>by chance</u>, they encounter moister regions, the rate of water loss declines, causing the

animals to slow down. In very moist places, they may cease to move entirely. The result of this automatic reflex behavior is that the animals do not remain in dry places for very long but, instead, aggregate in moist spots where they are in little danger of desiccation. So, isopods find moist places quite by accident (that's why the method is "risky"), but once they find these places, they tend to remain in them by becoming relatively inactive. It is this behavior which your students can explore in the activities that follow.

WHERE CAN YOU GET ISOPODS?

You can collect isopods from underneath rocks, bark, wood piles and decaying logs. Depending on where your school is located, a class collecting trip around the school grounds may yield a sufficient number of isopods to carry out the activities. Or, you could assign each of your students the task of collecting several isopods from around his/her neighborhood. Sometimes, isopods can be found under rocks in one's own back yard. They are easily kept alive for several weeks in a plastic bag containing some moist soil and leaf litter. Alternatively, isopods of the genus Porcellio can be purchased from a biological supply company for about $10 per 24 animals. You can keep the animals permanently in a classroom terrarium for further study (see Kramer, 1987 for suggestion on how to set up a classroom terrarium).

THE DRY AND MOIST SIDE OF AN ISOPOD'S LIFE

A.) Orientation and Experimental Procedures

Your students can investigate the reactions of isopods to dryness and moisture by preparing a simple choice chamber like the one shown in figure 1. You need a transparent container (plastic box, glass bowl, etc.) with a bottom length or diameter between 20 and 30 cm. Line the bottom of the container with two pieces of paper toweling, one dry, the other wet (but not dripping wet), separated in the middle by a 2 cm gap (see fig. 1). The paper toweling should fit snuggly against the bottom of the chamber to prevent the animals from crawling under the paper. Place the chamber in an area of the room where the light reaching the various parts of the chamber is fairly equal and constant (light should be a "controlled variable"). It is best to close the blinds or curtains of any windows. Have your students add 10 isopods to the 2 cm "neutral zone" (gap) between the dry and wet paper toweling. Isopods can be handled (gently) with fingers. They do not bite. Leave the chamber uncovered and let the animals get used to the chamber environment (this is called acclimation) for about 10 minutes before having your students begin their observations.

You can use the 10 minute acclimation period to review procedures and to encourage students to generate questions and to formulate hypotheses and predictions about how the isopods will behave inside the chamber. Be sure to ask your students to give the reasons behind their hypotheses or predictions. Following

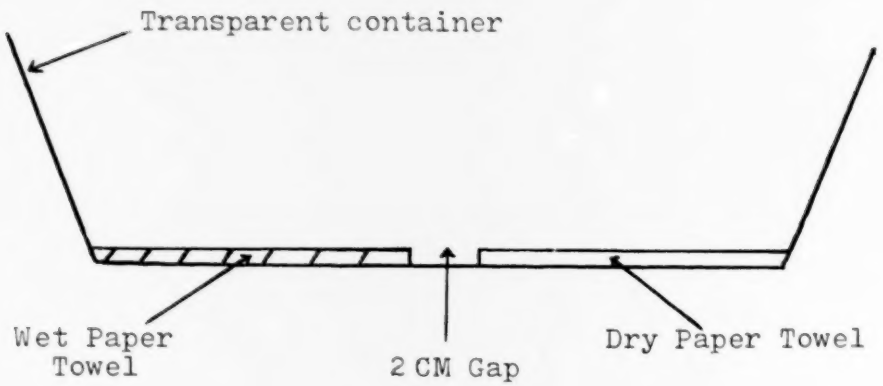

Figure 1. Isopod chamber with a 2-centimeter gap between wet and dry paper toweling.

ISOPOD (actual body length: 10-15 mm)

this, you might ask students to pay particular attention to these observations:

(1) Is there a difference in how fast the animals move on the wet and on the dry side?

(2) Do the animals remain motionless more frequently and for longer periods of time on one side than on the other?

(3) Is there a difference in the number of isopods found on the two sides during the observation period?

Encourage students to formulate hypotheses and to make predictions with regard to these three questions before they begin their observations. And always ask your students to support their hypotheses and predictions with reasons, so that you can determine how and what they are thinking.

Have students construct a data table similar to the one shown in table 1. The purpose of such a table is to permit systematic recording of the quantitative data necessary to answer question #3 above. The number of isopods on the wet and on the dry side of the chamber are counted at half-minute intervals over a 15 minute observation period (following the 10 minute acclimation period). One student can be the timekeeper. Several others can record the behavior of the animals on the two sides (to answer questions #1 and 2, above) and can make the appropriate counts every half minute. Any animals that are in the 2 cm gap area at the time a count is to be made are not counted. At the end of 15 minutes, students can calculate the total number of isopods that occurred

Table 1. Data table for recording the number of isopods on dry and wet paper toweling.

Time (minutes)		Number of Isopods on dry side	Number of Isopods on wet side
0.0	(Start)	6	4
0.5		5	5
1.0		3	7
1.5		5	5
2.0		4	6
2.5		2	8
3.0		5	5
.		.	.
.		.	.
.		.	.
15.0	(End)	4	6
	Total:	_____	_____
	Average per observation (Total÷31):	_____	_____

on each side, and the average (mean) number of isopods on each side, per observation (mean = total isopod count on wet or dry side divided by 31; 31 = total number of observations, at half-minute intervals, within 15 minutes). One way of graphing these data is shown in figure 2. Your students may suggest other creative methods of graphing their results (see Breit, 1987 for some interesting graphing methods that can be used with upper elementary and middle school pupils).

Caution your students not to move around too much while making their observations. You might ask them why unnecessary movement in the vicinity of the experimental chamber should be avoided. Quite often, students will offer the proper explanation: such movement could disturb the animals or might result in variable shadows that could influence the animals' behavior. Also, I have found that some students get impatient and start tapping the chamber when animals remain motionless for a long time. Students should be cautioned not to do this since it introduces an uncontrolled and unnatural variable into the experiment. There is, of course, a very good reason (the reflex reaction discussed above) why the isopods may remain motionless for some time, paricularly on the moist side of the chamber.

It is best to have several experimental set-ups so that results can be compared and pooled during post-activity discussions. It is important that, during these discussions, students are asked to analyze their own preliminary hypotheses and predictions in light of what they actually observed. This will reveal how the students

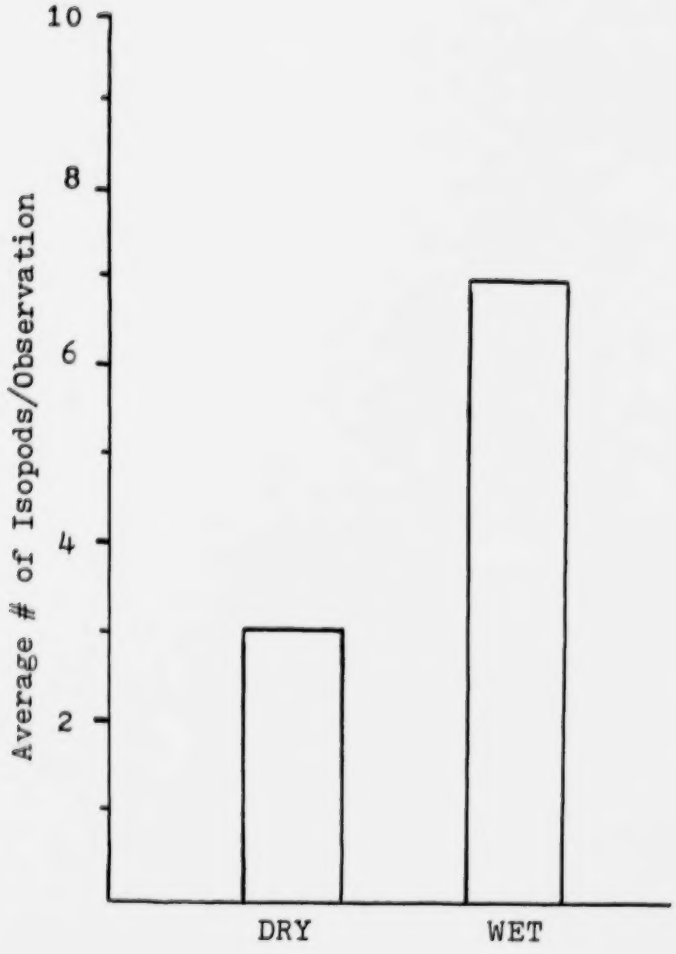

Figure 2. One possible method of graphing the results in table 1.

are thinking, and may also expose misconceptions in need of correction. You should guide these discussions in light of the background information presented earlier.

B.) The Reasoning Process

After reviewing their descriptive and quantitative data (which should show a greater number of isopods on the moist than on the dry side of the chamber), students will often suggest two reasons for the results: (1) isopods probably have some kind of moisture sensing device that guides them away from dry places and towards moist places, and (2) isopods must "like" moist places more than they do dry places. Both of these deductions are essentially incorrect.

Although the idea that isopods might have a moisture-sensing device is not unreasonable, you will have to explain to your students that biologists have not found moisture sensing receptors in isopods. If that is the case, how do these animals find moist places? If you guide the discussion skillfully, you should eventually get a response similar to the following, given by one of my students: "isopods must just walk around until they accidentally bump into the moist paper towel." The key concept here is accidentally.

At this stage of the analysis, your students will be aware of two things: first, that more isopods occurred on the moist side than on the dry side during the 15-minute observation period and, second, that isopods apparently find moisture accidentally. The

next logical question to ask your students is this: "Based on your observational (descriptive) evidence of the isopods' behavior in the chamber, why do you think more of them congregated on the moist side than on the dry side?" Note that I have stressed (by underlining) "based on your observational evidence". This is important because, unless you direct your students to the qualitative evidence they collected during the experiment, they will tend to respond to this question by saying: "More isopods were found on the moist side because isopods probably like moisture". Later, I will discuss why the proposition "isopods like moisture" is vague, inconclusive and technically incorrect. But it is a favorite proposition offered by students to explain the greater number of isopods on the moist side, and it is bound to crop up at some point in the discussion of the experimental results. You can, perhaps, momentarily deter your students from using this line of reasoning by directing them to their observations of the isopods' behavior inside the chamber. Once again, the question is: "Based on the evidence you collected, why do you think more ispods were found on the moist side than on the dry side?" You might want to supplement this general question with the more specific focus questions presented earlier: "Did the isopods seem to walk faster on one side than on the other?" "Did the isopods seem to 'rest' more frequently and for longer periods of time on one side than on the other?" Careful analysis and discussion of the descriptive data on the isopods' behavior should lead students to the important proposition that isopods congregate and remain longer on the moist side because their overall activity

is lower on this side than on the dry side. In other words, on the dry side, the animals tend not to rest but to keep moving; thus, they do not stay on the dry side for very long. When they encounter the moist paper towel, they tend to slow down and to remain motionless, and that is why they will occur more frequently on the moist side.

But this does not complete the reasoning process. WHY do the isopods slow down on the moist side and move more rapidly on the dry side? There are no observational data to answer this question, because it involves the reflex reaction discussed earlier. The chain of events that control the reflex reaction (i.e., the amount of water that an isopod loses by evaporation depending on the degree of dryness of its immediate environment, which, in turn, dictates its rate of locomotion) are invisible. Most likely, you will end up having to explain this reflex reaction to your students.

In any event, the above question, "Why do isopods slow down on the moist side and move more rapidly and rest less frequently on the dry side?" often leads to lively discussions and some rather unusual explanations and hypotheses. But here again, students will often suggest that isopods must "like" or "prefer" moist places more than they do dry places. After all, if you do not like some place (because it's too dry, for example), you will try to get out of there -- fast. Whereas, if you like some place (because it's nice and moist, for example), you will be inclined to stay there. The usual reason students give for this "liking" or "preference"

for moisture on the part of isopods is quite sound -- namely, that the isopods are in less danger of "drying up" when they are in moist places. This is certainly correct, and here you have some sound reasoning to build upon. BUT! The notion of "liking" or "preference" is inaccurate and misleading. Why?

With words such as "like" or "prefer", we have an example of how everyday language usage, when applied to the behavior of "lower" organisms, results in a subtle kind of anthropomorphism (or, anthropocentricism) -- the projection of human-like qualities and capabilities onto non-human living things or objects. The words "like" and "prefer" clearly suggest volition and choice. Volition and choice are not generally part of the behavioral repertoire of "lower" organisms. The uniqueness of humans is that they can have voluntary likes, dislikes and preferences, and that they can act on these, as well as on their environment, by the use of reason. "Lower" organisms generally cannot do this. Rather, they react to their environment; the environment acts on them and, to a large extent, controls them. "Lower" organsims are, for the most part, "the play-things of their environment", to paraphrase a well-known German ecologist. When students (and sometimes scientists, for that matter) fall into the subtle trap of using words such as "like" or "prefer" to explain the behavior of "lower" organisms, they are using words that reflect a human perspective. The words become a "linguistic trap". You will note that I have fallen into this same trap by calling the isopod test chamber a moisture "choice" chamber, for lack of a better, ordinary, descriptive term. From the human perspective, there is

clearly a choice here -- a choice between a dry and a moist paper towel. From an isopod's point of view, there really is no choice, in the sense of "volition". Why?

When an isopod finds itself on the dry side, it is highly unlikely that it thinks to itself: "Boy, it's really dry here; I don't 'like' it; I'm beginning to lose a lot of water by evaporation; I better get out of here and look for a moist place before I dehydrate and die." Instead, what seems to happen is that the increased rate of evaporative water loss from the isopod's body initiates an involuntary nervous reflex that causes its locomotor appendages to move more rapidly. In other words, its "legs" start to move back and forth really rapidly. This increase in the rate of locomotion increases the chances that the isopod will move out of the dry area and, perhaps, into a place with more moisture. And when, quite by accident, the isopod reaches a moist place, it is again highly unlikely that it will reflect: "Ah, a nice moist place; I really 'like' it here; I'm not losing much water and there's no danger of dehydration; I think I'll stay here." Rather, the lower rate of evaporation of water from the animal's body in moist places initiates a reversal of the above involuntary nervous reflex, causing a reduction in, or cessation of, locomotor activity (i.e., the isopod's "legs" slow down or stop moving altogether). The result of this lowered activity is that the isopod will tend to remain (inactive) in a moist place, until disturbed by some other environmental stimulus. In short, an isopod's reactions to moisture and dryness are controlled by automatic, involuntary nervous reflexes (analogous to the

knee-jerk reflex in humans) over which the animal has little or no control. There really is no choice.

I have found that the elementary and secondary preservice teachers and the high school biology students I have taught in the past were capable of understanding and "reasoning through" the chain of events I described above, with careful guidance. The notion that there are certain words in our ordinary, everyday english vocabulary (such as "like" or "prefer") that are applicable primarily to our human condition, but not to the actions and behaviors of other organisms, can be an eye-opening experience for some students. I believe it is important to teach students the skill of occasionally "stepping out or beyond" their human perspective and to look at life from a different point of view; in this case, from an isopod's "point of view". This is not easy. But unless students are taught to do this, they may develop, or be saddled with, fundamental misconceptions that will make subsequent learning of major biological principles, such as evolution and natural selection, very difficult. I will say a little more about this general topic in my concluding comments, but now, I want to introduce several other activities related to the one I have just described.

SOME INTERESTING VARIATIONS

There are several informative variations to the above activity, both of which require the use of only one isopod. All of the concepts, principles, explanations and reasoning processes

discussed in relation to the previous activity also apply to these variations. One advantage of these variations is that they permit careful observation of a single animal.

Variation #1:

A single isopod is added to the 2 cm gap in the chamber and is allowed to acclimate to the chamber environment for 10 minutes before the observations are started. In this variation, students determine the actual amount of time the isopod spends on the dry and on the moist side during a 15 minute observation period. This method requires a good deal of cooperation and teamwork. I usually have 3 students working in a group. The first student is the general timekeeper and keeps track of when the 15 minutes are up. He/she also has the responsibility of recording descriptive (qualitative) observations on the general behavior of the animal on the two sides of the chamber (as in the first activity). The second student keeps track of the amount of time the isopod spends on the dry side, while the third student records the time the isopod spends on the moist side. Both of these students need either stopwatches or watches with second hands.

Students begin their observations when the animal is either on the moist or on the dry side (rather than in the gap region). For example, if the animal is on the dry side at the beginning of the experiment, student #2 starts timing (as well as the general time keeper). As the animal moves from the dry side into the gap zone, student #2 stops timing and records the length of time the animal spent on the dry side. If the animal then moves on into the moist

side, student #3 starts timing -- and so on, back and forth. This procedure usually requires some preliminary practice. At the end of the 15 minutes, the individual times are added separately for the dry and for the moist side to determine the total amount of time the animal spent on each side during the 15 minute observation period. The total times for the dry and moist sides may not add up to exactly 15 minutes, for several reasons. First, there are bound to be some timing errors. And, second, the animal may spend some time in the gap zone between the dry and moist sides. One way of graphing the final results is presented in figure 3.

Variation #2:

A single isopod is added to the 2 cm gap zone in the chamber and is allowed to acclimate to the chamber environment for 10 minutes before the actual observations are started. In this variation, students record the position (dry or moist side) of the isopod at 15 second intervals over a 15 minute observation period (See table 2). If the isopod happens to be in the gap zone at the time an observation is to be made, its position is not recorded (indicated by the dashes in table 2). As in the previous activities, students should make and record descriptive observations on the behavior of the animal on the two sides. At the end of 15 minutes, the position records (the X's in table 2) are tallied for each side. These data may then be graphed as shown in figure 4.

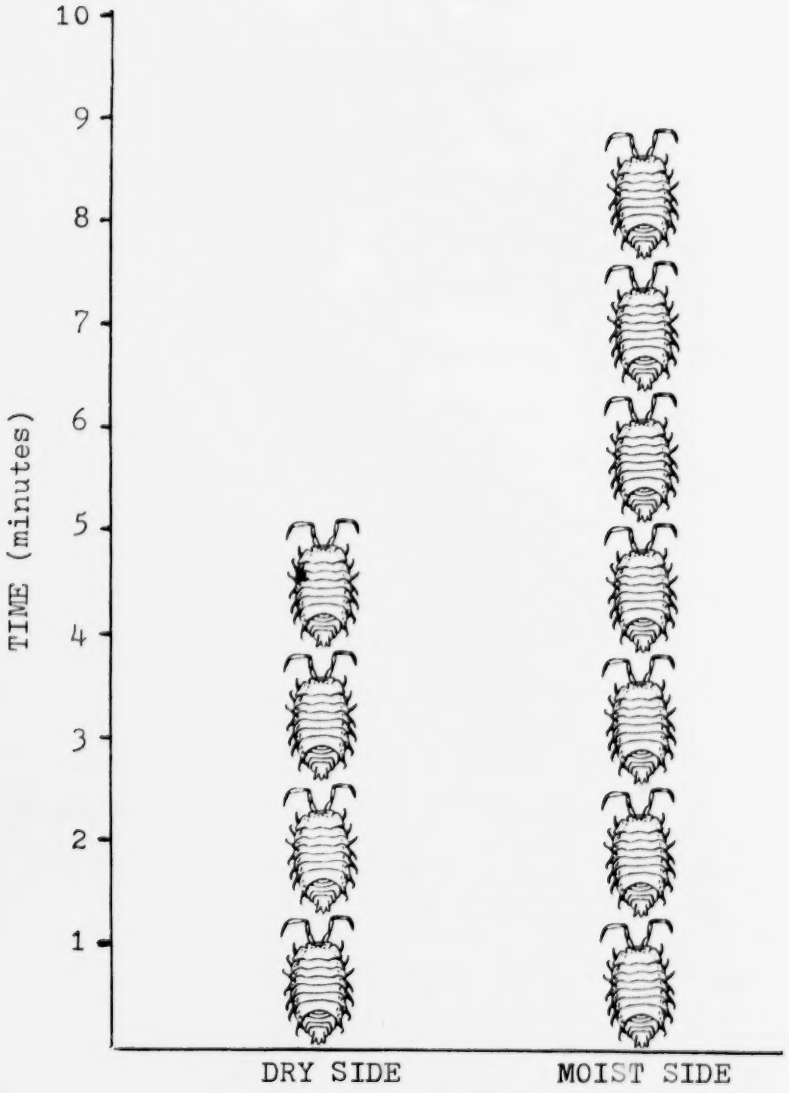

Figure 3. One method of graphing the amount of time a single isopod might spend on the dry and moist side of a moisture choice chamber during a 15-min. observation period.

Table 2. Data table for recording the position of one isopod in the moisture choice chamber.

Time (min:sec)		Position of Isopod	
		Moist Side	Dry Side
0:00	(Start)	X	
0:15		X	
0:30			X
0:45		—	—
1:00			X
1:15		X	
1:30		X	
1:45			X
2:00			X
.			
.			
.			
15:00	(End)	X	
	Total:	_____	_____

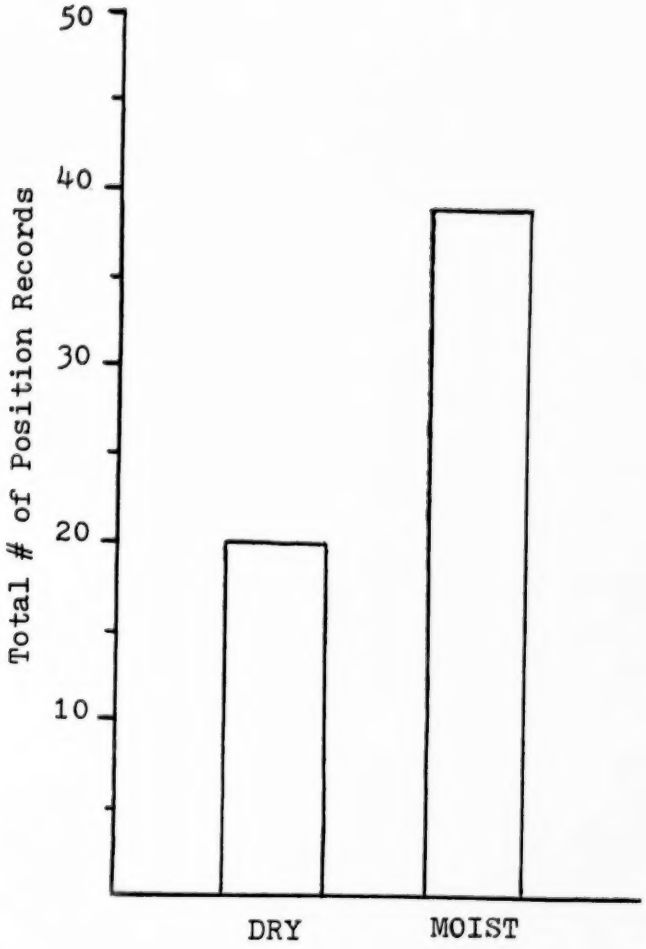

Figure 4. One possible method of graphing the results in table 2.

SUMMARY

I usually establish two groups of students for each of the three activities. This requires a total of six chambers and 24 isopods. Since the activities are variations on a common theme, the qualitative and quantitative data collected are complimentary and can be compared during post-activity discussions.

Invariably, some students will ask additional questions, such as "How will the isopods behave, and what kind of results will I get, if both pieces of paper toweling are dry, or moist?" Or, "What will happen if I shine a light on the moist side, or on the dry side?" There are many opportunities for additional explorations and for formulating and testing other hypotheses using this simple equipment. So, allow your students' imaginations to roam and don't stop by investigating only the moist and dry paper towel side of an isopod's life. What about exploring the moist paper towel versus the moist soil side of an isopod's life? Or, why not look at the dark and bright side of an isopod's life?

ADDITIONAL COMMENTS AND CONSIDERATIONS

A.) A Brief Survey

Isopods are ideal classroom animals. They are easy to collect and to maintain and, because they are relatively slow-moving, they are also easy to observe. I had always been under the impression that isopods were a commonly-used classroom animal. However, after

conducting an informal and, admittedly, somewhat unscientific survey of 10 middle and high school life science textbooks, I was surprised to find that only three of them mentioned isopods and only one included an activity similar to the first one discussed in this paper. The activity was included in a section of the textbook that dealt with the water and moisture requirements of terrestrial animals. Students were asked to place 10 isopods into a chamber similar to the one I described earlier, and to count how many isopods occurred on the dry and moist side after 15-20 minutes. Several follow-up questions asked students to offer suggestions (hypotheses) as to why the isopods' behavior (tendency to aggregate on the moist side) might have survival value in nature. No mention was made of (a) specific adpatations to the terrestrial environment, particularly with regard to moisture and water requirements, and (b) the isopods' moisture-locating mechanism. Consequently, an ideal opportunity was missed to discuss the critical concept of "biological adaptation" in a meaningful way. And, it is the concept of adaptation -- those characteristics and mechanisms an organism has evolved that enable it to survive in certain environments and, perhaps, not in others -- that provides the <u>meaning</u> behind an isopod's reactions to moisture/dryness and, for that matter, behind much of what we observe in the living world.

B.) <u>Further Comments on the Reasoning Process: WHAT-WHY-HOW?</u>

In figure 5, I have outlined some of the basic concepts and reasoning processes related to the "water-moisture" problem of

isopods. The reasoning process outlined in this diagram can be applied to the investigation of other adaptations an organism may have evolved in response to a given environment or environmental factor. The thinking process revolves around three common queries: WHAT? WHY? and HOW? The first step is to state the inquiry problem. For example: "Do isopods aggregate in moist or in dry places and do they behave differently in these places, other factors being equal?" After the inquiry problem is stated, observational facts (data) are collected through experimentation and careful observation. The observational facts represent the WHAT: what happened and what was observed. Collectively, observational facts represent the empirical evidence that provides the framework for further thinking, reasoning, hypothesizing and experimentation. In the present case, one basic observational fact is that isopods tend to aggregate in moist places as opposed to dry places (supported by quantitative data). An additional, and related, observational fact is that the isopods walk faster on the dry side than on the moist side and remain motionless for longer periods of time on the moist side.

But, what are the reasons behind the observational facts? This initiates the WHY phase of the thinking process. Unless this is explored in some depth (with the guidance of a knowledgable teacher) and, when appropriate, linked to the HOW phase, students may leave the learning task with vague, nebulous notions and, worse yet, with fundamental misconceptions. If it is true that a basic aspect of human nature is a quest for meaning (which may depend on the nature of the learning task/situation), then a

The "Water-Moisture Problem" in Isopods

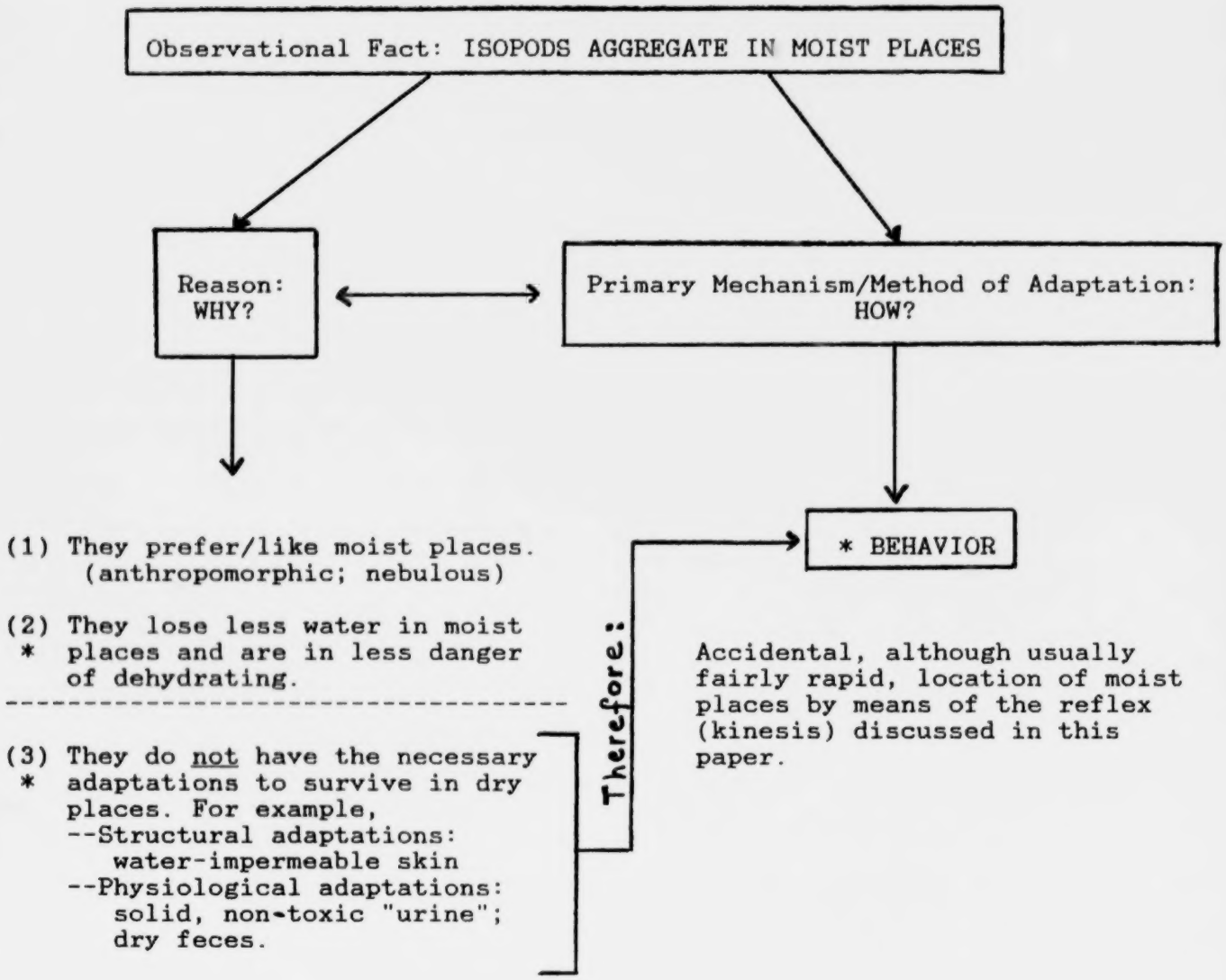
Observational Fact: ISOPODS AGGREGATE IN MOIST PLACES
Reason: WHY?
Primary Mechanism/Method of Adaptation: HOW?
(1) They prefer/like moist places. (anthropomorphic; nebulous)
(2) They lose less water in moist * places and are in less danger of dehydrating.
(3) They do not have the necessary * adaptations to survive in dry places. For example,
--Structural adaptations: water-impermeable skin
--Physiological adaptations: solid, non-toxic "urine"; dry feces.
Therefore:
* BEHAVIOR
Accidental, although usually fairly rapid, location of moist places by means of the reflex (kinesis) discussed in this paper.

Figure 5. The "water-moisture" problem in isopods: fundamental concepts and ways of thinking about it.

superficial investigation of a scientific phenomenon may force students to interpret the phenomenon within the context of their own limited experiences and pre-conceived notions. There is ample evidence in the science education research literature suggesting that this can perpetuate deep-rooted misconceptions, establish new ones and, consequently, make future meaningful learning more difficult (Helm & Novak, 1983). This does not mean that, as teachers, we should simply supply students with the "correct scientific conception" or the "correct" WHY's and HOW's. For a variety of reasons, this is unsatisfactory and insufficient for meaningful learning to occur (Helm & Novak, 1983; Champagne and Klopfer, 1984). According to cognitive learning theorists, learning tends to be more meaningful when the learner is actively involved in the "meaning-getting" process. Thus, students should be encouraged to formulate and test their own hypotheses and to express their own ideas about the WHY's and HOW's, something which I have stressed in the first part of this paper. It is through this process that, <u>with the guidance of the teacher</u>, students' misconceptions are revealed and hopefully corrected. Fundamental misconceptions are exposed when students are asked to reveal their thinking and reasoning patterns, and this can only be accomplished by a fairly comprehensive analysis of the scientific phenomenon, concept or principle under investigation.

In figure 5, three basic propositions are stated as possible reasons WHY isopods tend to aggregate in moist rather than in dry places. A superficial treatment of the topic (as in the textbook activity mentioned above) is likely to lead students only to

propositions (1) and (2), after which further inquiry and reasoning is apt to be terminated (indicated by the dashed line in figure 5). Earlier, I discussed why proposition (1) (isopods prefer/like moisture) is fundamentally in error; it represents a subtle misconception rooted in linguistics and arising as a consequence of analyzing biological phenomena from a strictly human perspective, i.e., attributing human qualities and capabilities to non-human living systems. Unless misconceptions of this kind are cleared up early in a student's study of biological phenomena, he/she may subsequently have difficulties grasping the highly materialistic-mechanistic concept of natural selection, the currently accepted mechanism of biological evolution.

Proposition (2) - that isopods lose less water in moist places and are in less danger of dehydrating in moist than in dry environments - is essentially correct. However, unless the reasoning process is continued beyond this point, students may simply link propositions (1) and (2) into the single proposition: Isopods <u>like</u> moist places because they are in less danger of drying out in moist than in dry places. Terminating the inquiry process with the attainment of proposition (2) is, or ought to be, intellectually unsatisfying, as it leaves open the question: WHY do isopods tend to lose more water in dry places than in moist places?

The answer to this last question involves two interrelated levels of explanation. The first level is related to a purely physical phenomenon. Throughout this paper, I have assumed that

both the teacher and the student understand this physical phenomenon, an assumption which may not be warrented. Briefly, any terrestrial organism is bound to lose somewhat more water, by evaporation from its body, in a dry than in a moist environment. The air in a moist environment is apt to have a higher relative humidity, which tends to decrease the rate of evaporative water loss from the body (for example, the reason you feel "sticky" on a humid day is because the high humidity/moisture in the air tends to prevent the evaporation of sweat from your skin). The opposite is true in dry environments; here, the generally low relative humdity tends to increase the rate of evaporation of water from the body.

It is the second level of explanation with regard to the question "Why do isopods tend to lose more water in dry places than in moist places?" which is of primary concern here, because it leads to proposition (3) (figure 5), which directly addresses the concept of biological adaptation. Isopods do not have the necessary structural and physiological adaptations to prevent excessive evaporative water loss from their bodies in dry environments. Consequently, they must "rely on" (have evolved) behavioral reactions or mechanisms that keep them in moist places. That is, behavior is one of the primary meachanisms (the HOW?) by means of which isopods have adapted to the terrestrial environment or, more specifically, whereby they appear to have solved the "water-moisture problem" confronting them in terrestrial habitats.

To complete the reasoning process, students need to understand the precise nature of an isopod's behavioral reaction to moisture and dryness. This is because animal behavior, when analyzed through the perceptual-conceptual goggles of human experience, may be erroneously interpreted to involve volition and choice. Even after students have gained some insights into the reasons isopods aggregate in moist places (the left side of fig. 5), incomplete knowledge of the nature of the bahavioral mechanism (the right side of fig. 5) may lead to a set of related propositions or assertions similar to the following: Isopods aggregate in moist places because they <u>like</u> moist places; the observational evidence for this is that they tend to be much less active in moist places than they are in dry places and therefore tend to remain in moist places for longer periods of time; the reason isopods <u>like</u> moist places is because they lose less water in such places than they do in dry places and are, therefore, in less danger of dehydrating; isopods do not have the necessary structural and physiological adaptations to prevent excessive water loss in dry places and thus <u>choose</u> moist places in which to live. This approximates a set of propositions frequently offered by my students before discussion of the reflexive nature of the moisture-locating mechanism. In a sense, students almost have no "choice" but to resort to such anthropocentric explanations because they are often unfamiliar with the involuntary controls the environment exerts on "lower" organisms. To understand the bahavioral reactions of isopods and other "lower" organisms to environmental factors requires

replacing vague anthropocentric words, concepts and interpretations with clear, mechanistic explanations.

C.) Why The "Risky Reflex Method" And Not Some Other?

For the truly curious student there remains the question: Why have isopods evolved such a risky mechanism for finding moisture? Or, why haven't they evolved humidity or moisture receptors that could guide them, in a direct and non-random manner, to moist places? The answer to this question involves some intelligent speculation based on general biological and evolutionary principles. Isopods are rather sedentary animals. They do not roam widely or wander too far from their moist hiding places. Thus, the pressure ("selection pressure") for the evolution or development of sensitive moisture/humidity receptors has probably not been very great in these animals. If isopods roamed far and wide, perhaps frequently wandering into dry habitats, then the pressure to evolve efficient moisture-detecting devices probably would have been much greater in their evolutionary history. But, in view of their sedentary life-styles and the rather high and constant supply of moisture available in the microhabitats they occupy, precise moisture sensors are probably unnecessary. In fact, such devices may even be superfluous and energetically uneconomical. All biological functions require a certain amount of energy. It is quite possible that the operation of precise moisture/humidity sensors would be more costly, energetically, than is the operation of the comparatively "simple" reflexive moisture-locating mechanism used by isopods. Thus, isopods may be saving energy with

the latter mechanism -- energy which the animals can channel into other critical life functions, such as more efficient food-locating mechanisms or reproductive activity, for example. But the critical test of any important biological adapation ultimately is this: Does it work? And the "risky-reflex" moisture-locating mechanism (adaptation) of isopods does, indeed, seem to work -- because if it didn't, we would not expect isopods, as we currently know them, to be with us anymore. They would have long since "dried up", so to speak.

D.) How General is the "Risky-Reflex" Moisture-Finding Method?"

If the reflex method of locating moist places works for isopods, does it work for other terrestrial invertebrates? Or, have similar methods of finding moisture evolved in other terrestrial invertebrate groups? It appears that earthworms, centipedes and millipedes, invertebrates that live in microhabitats similar to those inhabited by isopods (see Kramer, 1987), use a moisture-locating mechanism resembling that of isopods. Even some "higher" animals, such as frogs, seem to have evolved reflexive mechanisms for finding moisture. For example, if a frog is placed in the middle of a small, square, dry room that contains some dishes of water in its four corners, the frog will jump around rather actively, and apparently haphazardly, until it "accidentally" lands in one of the water dishes, where it will tend to remain. If the same frog is placed in a large room, such as a classroom, it may dehydrate and die before ever reaching one of the water dishes. This suggests that frogs probably do not have

precise moisture sensors or receptors capable of guiding them towards moisture in a direct, non-random fashion. Most likely, frogs depend on a reflex mechanism similar to that of isopods.

After students have investigated the moisture reactions of isopods and begin to comprehend the fundamental concepts and processes involved, there are ample opportunities for them to explore the moisture reactions of other organisms. This can be the basis for some exciting individual research investigations and science fair projects.

E.) "Lower" And "Higher" Animals

Throughout this paper, I have put quotation marks around the words "lower" and "higher" when referring to organisms of varying complexity. This convention is observed by many authors of life science textbooks, although few of them ever make the effort to explain why they are following this practice. I want to present my reasons, which are related to fundamental principles of evolutionary biology.

The words "lower" and "higher", when applied to animals in general, and particularly when used to compare humans to other animals, may reflect anthropocentric biases at two levels. First, common usage of these words generally implies that "higher" is somehow "better" than "lower". Second, when these words are used in conjunction with an uncritical view of the evolutionary history of life on earth, they may lead to the false impression or conclusion that this evolutionary history is one of inevitable,

steady "progress" from less to more complex forms of life, culminating in the "highest" organism of all, Homo sapiens. Both of these views are essentially incorrect, in terms of modern conceptions of biological evolution.

"Higher" organisms, or those exhibiting greater relative complexity, are not necessarily "better" than "lower", less complex, organisms. Complexity is the result of evolution and selection pressures in local environments in which increased complexity is one way the adaptation between the organism and its particular environment is enhanced. That is, the environments and niches in which an organism evolved, over millions of years, determine to a large degree the structural complexity of the organism. The present-day tiger is relatively more complex than is the present-day isopod because the environments and niches in which the tiger's ancestors evolved imposed a set of environmental selection pressures that "shaped" an animal with relatively complex features --- keen vision and smell, well-developed musculature for speed, stripes for camouflage, sharp claws, etc. These "complex" features adapt the tiger to its particular environment and niche and, consequently, increase its chances of survival and continuity in that particular environment/niche. The present-day isopod, on the other hand, is relatively less complex than the tiger because the environments or niches in which the isopod's ancestors evolved imposed a different set of selection pressures resulting in a different level of complexity. But the critical point is that both the tiger and the isopod are adapted to their specific environments and niches to the extent that they

survive and perpetuate their own kind. And, in evolutionary terms, the survival and perpetuation/continuity of a species are the indicators of its success, no matter what the level of complexity may be. If an isopod is as well adapted to its environment/niche as tigers are to theirs, who is to say that the tiger is a "higher" or "better" creature? Or, to make the point in a somwhat extreme way, it is highly unlikely that a tiger-like animal could make a decent living in, or under, a decaying log.

The words "higher" and "lower", when coupled with an uncritical view of the branching bush of evolutionary history, may lead to the erroneous impression of an inevitable, steady "progress" from lower (less complex) to higher (more complex) forms of life through evolutionary time. There are, of course, trends of increasing complexity through evolutionary time, but these trends have usually been exaggerated and there is nothing inevitable about them. There are, indeed, more complex organs and organisms now than there were soon after the beginnings of life, but that is a matter of history. It is a matter of organisms moving into diverse environments and filling diverse niches, leading to different levels of complexity for survival and continuity. George Gaylord Simpson, an evolutionary biologist, conveyed this idea when he said: "The limb of a mammal cannot be considered an improvement over the fin of a fish because neither performs more effectively the functions of the other or adds to the function of the other".

The history of life on earth is not one of steady, stately progress towards "higher" life forms, but is marked by explosions, extinctions, starts, stops and, at times, "degeneracy" to lower levels of complexity. An example of the latter is the "degeneracy" of parasites. Many present-day parasites evolved from more "complex" free-living ancestors that lost their digestive tracts and their ability to manufacture digestive enzymes after adopting the parasitic life-style. This illustrates that a change in environment and niche can lead to a reduction rather than to an increase in complexity, if the reduction in complexity leads to better adaptation of the organism to its new environment/niche. For a blood-sucking parasite, a digestive tract and the enzymatic machinery for digesting food are superfluous, since the organism is obtaining pre-digested food from the blood of its host. The energy that would be required to maintain a digestive tract and to manufacture digestive enzymes can be more effectively used by channeling it into other processes -- such as the development of better blood-sucking structures, or increased reproductive output. Thus, either a reduction or an increase in complexity can lead to better overall adapation of an organism to a changed environment/niche. Organisms become better adapted to their local environments and niches, and that is all. There is no evidence of a "plan" leading inevitably towards "higher" things. For further insights into this general topic I refer the reader to an excellent set of essays by Stephen J. Gould (1977) and to Roger Lewin's (1982) general treatise on biological evolution.

F.) Science: Interplay Between Content and Process

The word "science" comes from the Latin "scientia", meaning knowledge. But science encompasses more than merely a body of knowledge (content). It also connotes a process, whereby "mutable truths" are ascertained by observation, experimentation, induction (establishment of general principles/theories from observational facts) and deduction (testing hypotheses and theories against experience). The proper conduct of science is an interplay between previously established concepts, principles and theories and the quest for new knowledge (or the refinement of previously attained knowledge). Science is a balance between content and process. This balance must also be achieved in science education.

The ideas an individual brings to the investigation of a scientific phenomenon influence the richness and quality of the hypotheses he/she will be able to generate with regard to that scientific phenomenon. We cannot think nor propose meaningful hypotheses without an adequate store of concepts related to the phenomenon we wish to investigate. That is why scientists engage in time-consuming "background research" before attempting to pose new inquiry problems or hypotheses. Early proponents of the "discovery approach" to teaching science in the classroom tended to overlook this basic fact, or to treat it too lightly, when they emphasized process, often at the expense of content. Conversely, teachers who emphasize content at the expense of process often fail to expose their students to those processes (critical thinking, drawing conclusions based on evidence, problem solving,

hypothesis formulation and testing) that make science meaningful and that may find application in non-science situations outside the classroom. For science to be meaningful, there must be a balance between content and process. You cannot have one without the other, without seriously distorting the essence of science.

Consider the following situation as an example of how content and process (problem-solving, hypothesis formulation and testing) interact. Suppose your car stalls on the highway. What do you do? You may start to formulate and test hypotheses as to the cause of the stalling. Your first inclination may be to formulate the following hypothesis: My car stalled because it is out of gas. You test this hypothesis by looking at the gas gauge. It registers half-full. Lack of gas does not appear to be the cause (of course, the gas gauge could be defective). The next step may involve looking under the hood of the car. This is where further hypothesis formulation ceases for most people, due to a lack of knowledge (content) about what goes on under the hood. But suppose you know a little about batteries. You may proceed to check the battery wires or the battery's fluid level. Or, suppose you know something about carburators. You may proceed to check that out..., and so on. The point is that the extent to which we can formulate and test meaningful hypotheses in a systematic way depends to some degree on the concepts we already have that are related to the phenomenon under consideration. The implication of this for teachers of science is: Provide your students with a basic conceptual framework related to the phenomenon being studied, through explanation and discussion, and <u>then</u> let them go and <u>do</u>

something with it (process). It is neither necessary nor desirable to explain "everything" about a certain phenomenon, but it generally is necessary and appropriate to provide a general conceptual framework that serves as an "anchor" for the initiation of systematic and meaningful hypothesis formulation and testing.

Novak and Gowin (1984) provide an excellent heuristic that stresses the interplay between content and process. They call it the "V" heuristic. Figure 6 shows a "V" analysis applied to the water-moisture problem in isopods. According to Novak and Gowin (1984),..."the Vee used as a heuristic with students helps them to see the interplay between what they already know and the new knowledge they are producing and attempting to understand...[it] helps learners to understand the process by which humans produce knowledge" (p. 57). The left side of the "V" (fig. 6) is the conceptual side, consisting of the theory, principles and concepts pertinent to the problem being investigated. This is the general conceptual framework that generates the focus questions (shown in the middle of the "V"). The focus questions generate the event or experiment, shown at the tip of the "V", as well as the methods and procedures (right side of the "V"). The event generates records/data, which may be "transformed" into graphs and tables to facilitate interpretation. From the records, graphs and/or tables, knowledge claims are generated -- i.e., what was learned. Finally, value claims are judgments concerning the overall worth of the investigation and the value of what was learned.

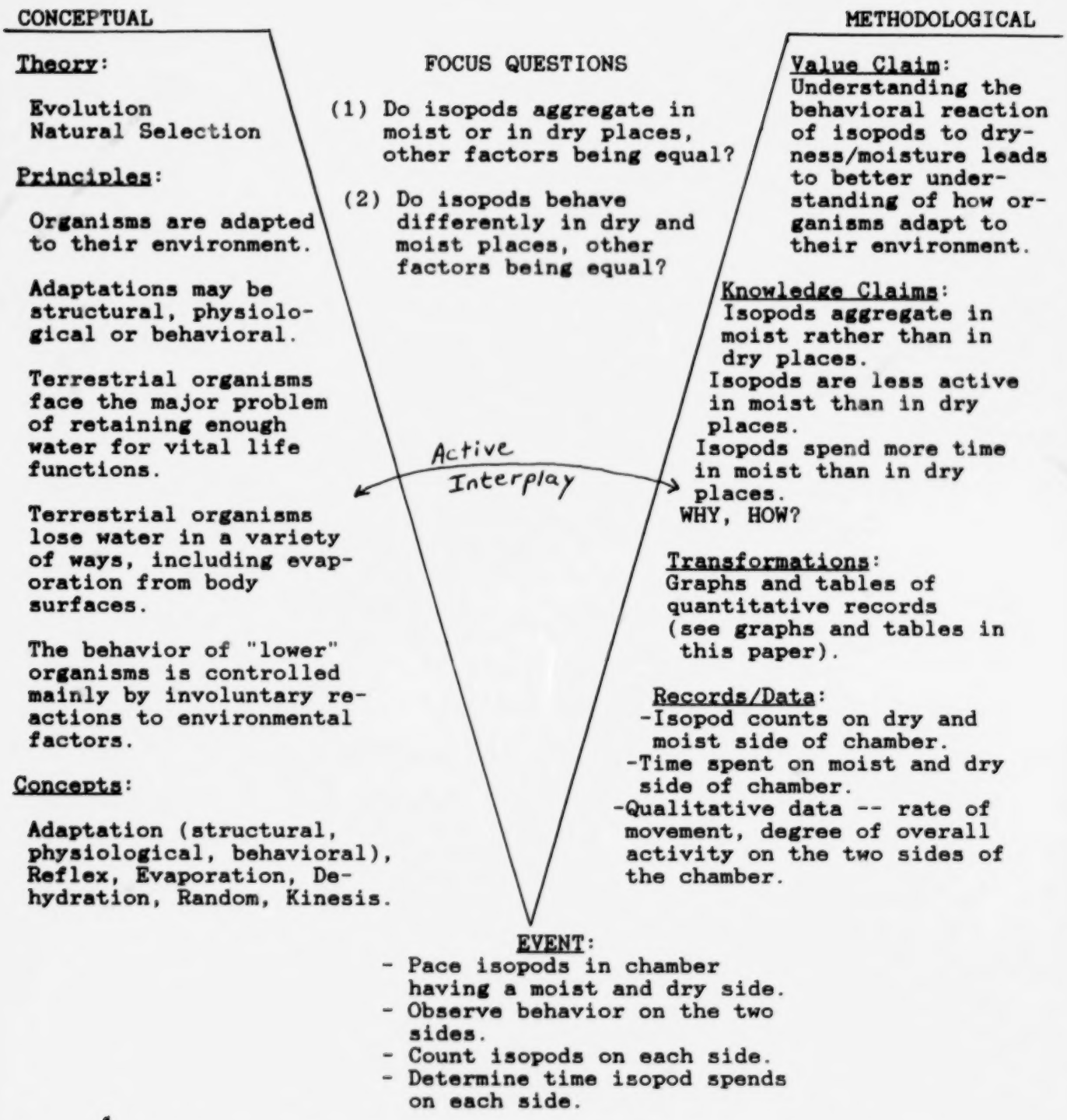
CONCEPTUAL
METHODOLOGICAL
Theory:
Evolution
Natural Selection
Principles:
Organisms are adapted to their environment.
Adaptations may be structural, physiological or behavioral.
Terrestrial organisms face the major problem of retaining enough water for vital life functions.
Terrestrial organisms lose water in a variety of ways, including evaporation from body surfaces.
The behavior of "lower" organisms is controlled mainly by involuntary reactions to environmental factors.
Concepts:
Adaptation (structural, physiological, behavioral), Reflex, Evaporation, Dehydration, Random, Kinesis.
FOCUS QUESTIONS
(1) Do isopods aggregate in moist or in dry places, other factors being equal?
(2) Do isopods behave differently in dry and moist places, other factors being equal?
Active Interplay
Value Claim:
Understanding the behavioral reaction of isopods to dryness/moisture leads to better understanding of how organisms adapt to their environment.
Knowledge Claims:
Isopods aggregate in moist rather than in dry places.
Isopods are less active in moist than in dry places.
Isopods spend more time in moist than in dry places.
WHY, HOW?
Transformations:
Graphs and tables of quantitative records (see graphs and tables in this paper).
Records/Data:
-Isopod counts on dry and moist side of chamber.
-Time spent on moist and dry side of chamber.
-Qualitative data -- rate of movement, degree of overall activity on the two sides of the chamber.
EVENT:
- Pace isopods in chamber having a moist and dry side.
- Observe behavior on the two sides.
- Count isopods on each side.
- Determine time isopod spends on each side.

Figure 6. "V" analysis applied to the water-moisture problem in isopods.

The critical aspect of the "V" is that it promotes the active interplay between what the student already knows (conceptual framework, or left side of the "V") and some related problem he/she is trying to solve by conducting an experiment or investigation (the "doing" or right side of the "V"). In other words, the data, results and knowledge claims that are generated on the right side of the "V" are constantly interpreted for meaning in light of the conceptual framework already in place while, at the same time, that conceptual framework may be modified and/or enriched by the knowledge claims generated by the investigation. In essence, the "V" is a model for thinking, problem-solving, hypothesis formulation and testing, and meaningful learning. It is a model for "doing" meaningful science. Novak and Gowin (1984) outline steps for the incorporation of "V" analysis into the science curriculum. "V" analysis can be used instead of, or as an adjunct to, the usual student laboratory report. The advantage of the "V" is that it enables the student to analyze his/her thinking and approach to an inquiry in a systematic and direct way. Novak and Gowin (1984) provide procedures for scoring the quality of students' "V" analyses, according to various criteria.

In figure 6, I have written "WHY and HOW" under the knowledge claim heading on the right side of the "V". WHY and HOW are not knowledge claims, of course. I have done this to emphasize that there are various aspects of the water-moisture problem of isopods that are not amenable to direct empirical testing. For example, the relationship between the evaporation of water from the body of

an isopod and the resulting locomotor reflex can only be inferred indirectly as a possible mechanism accounting for the observational evidence collected during the experiments. In most investigations, there are usually events that need to be inferred (or, speculated about) from the observational data, by relating these data to concepts and principles on the left side of the "V". In the case of the water-moisture problem of isopods, the WHY's and HOW's need to be explored during classroom discussions of experimental data and results, with the teacher's guidance.

In my view, science is not merely a systematic process for the attainment of knowledge. It is a systematic process for the attainment of knowledge and meaning. This should also be the aim of learning. Science is really nothing more than a systematic, structured form of everyday thinking and problem solving (consider the stalled car analogy given above). And, the scientific process does not end with the attainment of observational facts (the WHAT's). The discovery of a fact is only a beginning. It is the discovery of the meaning behind the fact or, the relationship between facts, which is the ultimate aim of science and which ought to be the goal of learning as well. When scientists or learners begin to look for the meaning behind the facts, they will invariably be engaged in hypothesizing, inquiry, the collection of additional evidence and observational facts, followed by further inquiry....., and so on. It is a never-ending chain of discovery and meaning-getting. The search for meaning -- for a way to explain the WHAT by asking WHY and HOW? (and, often also WHEN?) --

requires the active use of our most uniquely human capabilities, thinking and reasoning.

I have sometimes been surprised by the number of students I have taught in the past who appeared to be satisfied with the mere acquisition of a fact, without questioning its validity, meaning or relationship to other facts. To these students, learning "means" the accumulation of a catalogue of disconnected facts, and the ability to regurgitate these facts. I do not believe that this is a "natural" tendency. I think that this kind of "learning" is learned -- unfortunately, mostly, although not exclusively, in our schools. I believe, with Piaget, Bruner and others, that children (and I would include most adults) have an innate desire to make sense out of their experiences. Facts <u>are</u> important, of course, but not as an end in themselves. They are important because they provide the framework, and are the vehicles for inquiry, thinking and the acquisition of meanings (searching for the <u>relationship</u> between facts).

If our students' preoccupation with lists of facts is learned, then, I suppose, this preoccupation can be unlearned, to some extent. But this will not be easy. Witness, for example, the popularity of fact-oriented board games and television game shows such as "<u>Trivial</u> Pursuit" and "Jeopardy", to name just a couple. These games and television shows are not inherently bad, of course, but they do underscore our fascination with walking encyclopedias of factual information. And again, we <u>do</u> want to encourage our students to acquire facts (content), but as a means

for arriving at greater understanding and meaning and to serve as tools of inquiry, problem solving and thinking, rather than as an end in themselves. In the classroom, what is required are teachers who know their subject matter (content) and who are confident, enthusiastic models of inquiry (process), eager to explore with their students the HOW's and WHY's behind the facts (the WHAT's). The exploration of the meaning behind facts by hypothesis formulation and testing is at the heart of the scientific process. Thus, the practice of science in the classroom should involve an active interplay between an existing conceptual framework and systematic formulation and testing of hypotheses/problems generated by that conceptual framework. It is by this process that knowledge, reasoning and problem solving skills are enriched, modified and refined. There are ample opportunities to engage in this meaning-getting enterprise by using the multitute of events and objects offered to us by the natural world. Even a small, "simple" animal that lives under rocks and logs has some exciting tales to tell that can make you think and wonder.

**

GLOSSARY

ACCLIMATION -- the process whereby an individual organism adjusts, over time, to a set of environmental conditions or to a change in environmental conditions.

ADAPTATION -- any genetically controlled characteristic (structural, physiological or behavioral) that helps an

organism to survive and reproduce in the environment it inhabits.

CONTROLLED VARIABLE -- any factor in an experiment that is not allowed to vary and is kept as constant as possible throughout the experiment so as not to influence the experimental results; in the experiments presented in this paper, the only factor that should be allowed to vary is moisture (dry and moist side of chamber) since the purpose of the experiments is to determine how isopods react to different levels of moisture; all other factors (variables) should be controlled (kept constant) so as not to influence the results.

CRUSTACEAN -- a class of animals (invertebrates), consisting of about 31,300 species, characterized by an external skeleton (exoskeleton) and two pairs of antennae; they are found in marine, fresh water and terrestrial habitats (examples: crabs, shrimp, lobsters, barnacles, isopods).

EVOLUTION -- change in the genetic make-up of a species population over time.

EXOSKELETON -- the outer skeleton or body covering of a large group (phylum) of invertebrate animals called arthropods (including: crustaceans, spiders, insects); the exoskeleton is composed of a protein substance called "chitin"; the exoskeleton, even though external, is technically a skeleton, since its inner surface serves as points of attachment for body muscles.

GENUS -- a biological classification category consisting of very closely related species of organisms.

HABITAT -- the specific environment or place where an organism lives (example: forest, lake, pond, open field).

HEURISTIC -- something employed as an aid to solving a problem or understanding a procedure.

HYPOTHESIS -- an informed, educated "guess" to the solution of a problem, usually followed by testing or experimenting to determine its accuracy and whether or not it needs to be revised, modified or perhaps discarded in favor of a different hypothesis.

INVERTEBRATES -- animals without backbones; 95% of all known animals are invertebrates; the rest (5%) have backbones and are known as vertebrates (fish, amphibians, reptiles, birds, mammals).

ISOPODS -- a fairly large group of crustaceans living in marine, fresh water and terrestrial environments; they are charcaterized by a dorsoventrally (top to bottom) flattened body.

KINESIS -- non-oriented, random movement.

MICROHABITAT -- any smaller subdivision of a larger habitat; for example, in a forest habitat, a microhabitat may be represented by a decaying log - many small organisms make their living inside decaying logs; often, the physical environment inside a microhabitat differs from that of the larger habitat of which the microhabitat is a part; for example, the humidity or moisture inside or under a

decaying log may be higher than the overall humidity or moisture in the general forest habitat; thus, a microhabitat often is characterized by a "microenvironment" that is different from the overall "macroenvironment" of the larger habitat.

NATURAL SELECTION -- differential reproduction in a species population, leading to an increase in the frequency of some genes/genetic combinations (favorable adaptations) and to a decrease in the frequency of others (unfavorable adaptations); or, the process whereby individuals with favorable adaptations to a given environment tend to enjoy greater reproductive success than individuals that are less well adpated, leading to an increase in the adaptation of the species population to its environment.

NICHE -- the functional role of an organism in a biological community or habitat [example: "food niches" include producer (green plants), herbivore (plant eater), carnivore (meat eater), decomposer (bacteria and other organisms that feed on and decompose dead plant and animal matter].

REFLEX -- a simple, essentially automatic/involuntary response to a stimulus; example: loss of water (stimulus) in an isopod initiates a nervous reflex resulting in an increase in the animal's rate of locomotion.

SELECTION PRESSURE -- in a species population, the force or forces (e.g., environmental) driving genetic change and adaptation, resulting from natural selection.

TERRARIUM -- a chamber or container of some kind established to house (or simulate) a portion of some terrestrial habitat or biological community; example: a forest floor terrarium, a desert terrarium.

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APPENDIX 1.

MATERIALS LIST

The quantities indicated in this list are based on six experimental set-ups (2 groups of students working on each of the three activities described in this paper).

You will need:

1. 24 Isopods.
2. 6 isopod chambers; any square/round container (glass or plastic) with a bottom diameter or length between 20 and 30 centimeters.
3. 6 metric rulers (fewer, if shared).
4. At least 12 sheets of paper toweling (the towling in school rest rooms works quite well).
5. Water.
6. 2 stopwatches or 2 watches with second hands.
7. A wall clock.
8. A good supply of graph paper.
9. Scotch tape; you may need this to tape the "dry" paper towling to the bottom of the isopod chamber in order to prevent the ispopods from crawling under the paper.
10. A terrarium, or any sort of container (glass/plastic) with moist soil and leaf litter in which to maintain the isopods before conducting the activities. You can feed the isopods with pieces of raw potato.